Probing S-Process Yields of Field Carbon Stars by the Analysis of 21μm Post-AGB Stars*

M. Reyniers [1†]
and H. Van Winckel [1‡]

[1]Instituut voor Sterrenkunde, K.U.Leuven, Celestijnenlaan 200B, B-3001 Leuven, Belgium

Abstract: The observational data guiding the theoretical chemical evolutionary models of AGB stars come mainly from the analysis of intrinsic and extrinsic s-process enriched objects. The first are the stars of the M-MS-S-SC-C star sequence which is thought to reflect, at least partly, the evolution on the AGB of a single star towards an increasing C/O ratio. The second are all binaries with excess abundances acquired by mass-transfer from the companion which is now a white dwarf.

In this contribution we present a homogeneous abundance analysis of 21μm objects, which are carbon-rich probably single post-AGB stars. With their F to G spectral types a wide variety of chemical species can be studied quantitatively by using photospheric atomic lines. These objects are among the most s-process enriched objects known so far. We focus on the s-process distribution and the related neutron irradiation and compare the results with the enrichments observed in both intrinsic and extrinsic objects.

1 Introduction

A subgroup of field post-AGB stars shows in their mid-infrared spectra a 21μm emission feature. This feature is not found in AGB stars, nor in PNe, suggesting that the excitation and/or formation of its carrier is limited to the dust enveloppes of the transition objects. Although the nature of the 21μm feature is not known, a good correlation exists between the presence of circumstellar carbon molecules like C_2 and C_3 in the optical spectra and the presence of the IR feature.

Several studies were dedicated to reveal the chemical photospheric composition of the 21μm stars, confirming their post-3rd dredge-up character (large C/O ratios and s-process enhancements). Together with their carbon-rich dust enveloppes, spectral types and high luminosities, the 21μm stars are good candidate *post-carbon* stars. Since different authors use different line lists and atomic data, results are difficult to compare quantitatively. Therefore, a *homogeneous* (same method and line list) abundance analysis is presented in this contribution.

*based on observations collected at the European Southern Observatory in Chile (61.E-0426), and at Roque de los Muchachos at La Palma, Spain

†Scientific researcher of the Fund for Scientific Research, Flanders

‡Postdoctoral fellow of the Fund for Scientific Research, Flanders

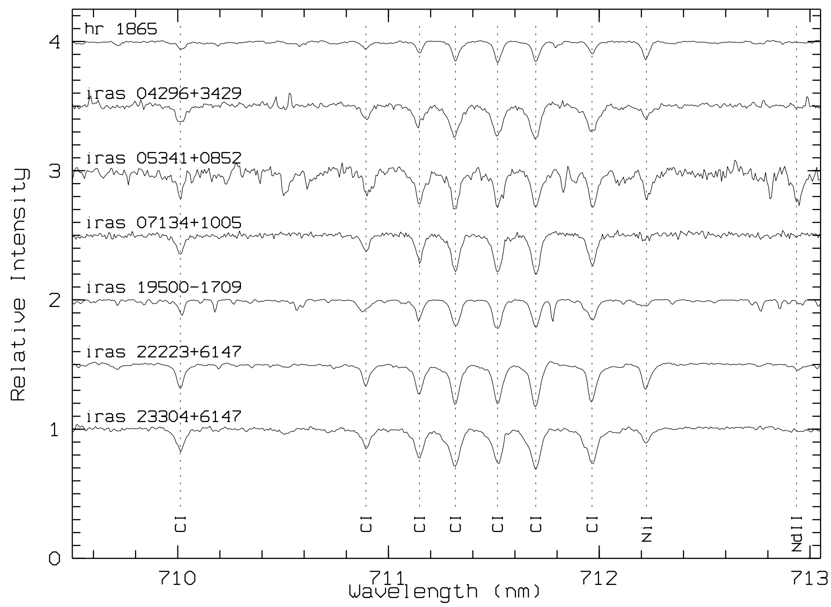

Figure 1: Sample spectra of the programme stars and HR 1865 around the red carbon multiplet. The stars are velocity corrected. On top, the spectrum of the reference star HR 1865 is plotted. This massive supergiant (FI0) has similar atmospheric parameters as the programme stars (Decin et al. 1998) but obviously no enrichment of helium burning products.

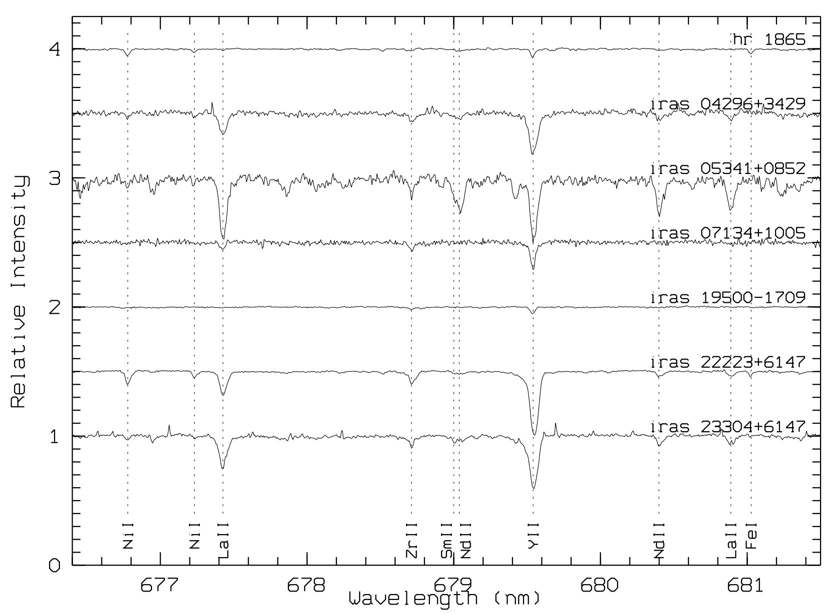

Figure 2: The region around $\lambda 679$ nm for the six programme stars and HR 1865. In this region, both lines of light (ls) and heavy (hs) s-process elements are present. Comparison with the normal supergiant HR 1865 proves that our stars are clearly s-process enhanced. The ratio of the line strength of the LaII-line at $\lambda 667.427$ nm and the YII-line at $\lambda 679.541$ nm for each star gives a very qualitative idea of the neutron exposure. From this spectral comparison we can expect a high neutron exposure for IRAS 05341+0852.

Table 1: Model parameters and metallicity of the six programme stars

	$T_{\rm eff}$ (K)	$\log g$	ξ_t ($\rm km\,s^{-1}$)	[Fe/H]
IRAS 04296+3429	7000	1.0	4.0	−0.6
IRAS 05341+0852	6500	1.0	3.5	−0.8
IRAS 07134+1005	7250	0.5	5.0	−1.0
IRAS 19500−1709	8000	1.0	6.0	−0.6
IRAS 22223+4327	6500	1.0	5.5	−0.3
IRAS 23304+6147	6750	0.5	3.0	−0.8

2 Observations and Analysis

Spectra were obtained using the Utrecht Echelle Spectrograph (UES) mounted on the 4.2m William Hershell Telescope (WHT) during several runs between 1992 and 1995. For one object (IRAS 07134), the NTT was used in combination of the EMMI spectrograph. For most spectra, we obtained a resolution of ∼50,000 and a S/N>100 (see Fig. 1 and 2 for sample spectra). Model atmospheric parameters (Table 1) were derived by the commonly used spectroscopic method: the effective temperature $T_{\rm eff}$ from the excitation balance of the FeI-lines, the surface gravity $\log(g)$ from ionisation balance between FeI and FeII and the microturbulence ξ_t by forcing the Fe abundance to be independent of the reduced equivalent width W_λ/λ of the FeI lines. Abundances were obtained with the Kurucz model atmospheres. Special attention was paid to accurate $\log(gf)$ values, using the most recent compilations. Only weak lines with equivalent widths smaller than 150 mÅ were used in the analysis.

3 Results

The results of our analysis are presented in Fig. 3. The **metallicity** relative to the solar value ranges from −0.3 to −1.0 (Table 1), indicating that our sample indeed consists of an old and hence low-mass population. From Fig. 3 it is clear that all stars display a huge photospheric **carbon** enhancement. This is illustrated in Fig. 1. **Oxygen** is also enhanced, but, especially for the cooler stars, an accurate oxygen abundance is hampered by the small number of lines. Accurate C/O ratios are therefore hard to obtain, but are found in between 1.0 and 2.9. The slight overabundances of the **α-elements** are considered to be normal for this metallicity range. The most convincing argument for the post-3rd dredge-up character of the studied stars is the huge enhancement in **s-process elements**. This is illustrated in Fig. 2. The 21μm stars turn out to be among the most s-process enriched objects known so far.

4 Discussion

4.1 Neutron Exposure

We defined for each star the [hs/ls] index as the ratio of heavy (Ba, La, Nd, Sm) to light (Y, Zr) s-process elements. The abundances of unobserved species were estimated using the tables of Malaney (1987). The [hs/ls] index is a good indicator for the *mean neutron exposure* τ_0, whereas [s/Fe] is a measure for the *total s-process enrichment*.

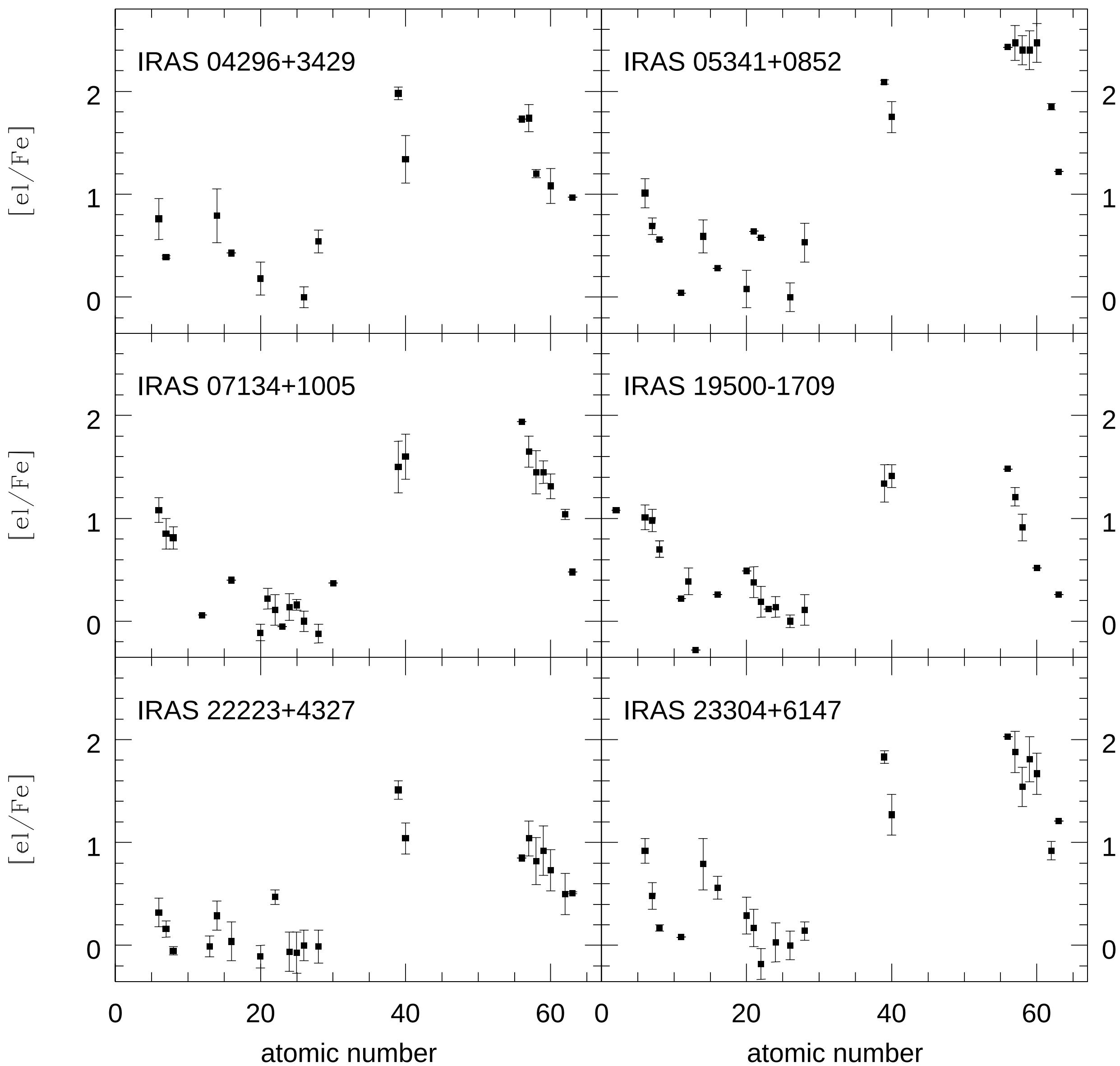

Figure 3: The abundances of our six programme stars relative to iron [el/Fe].

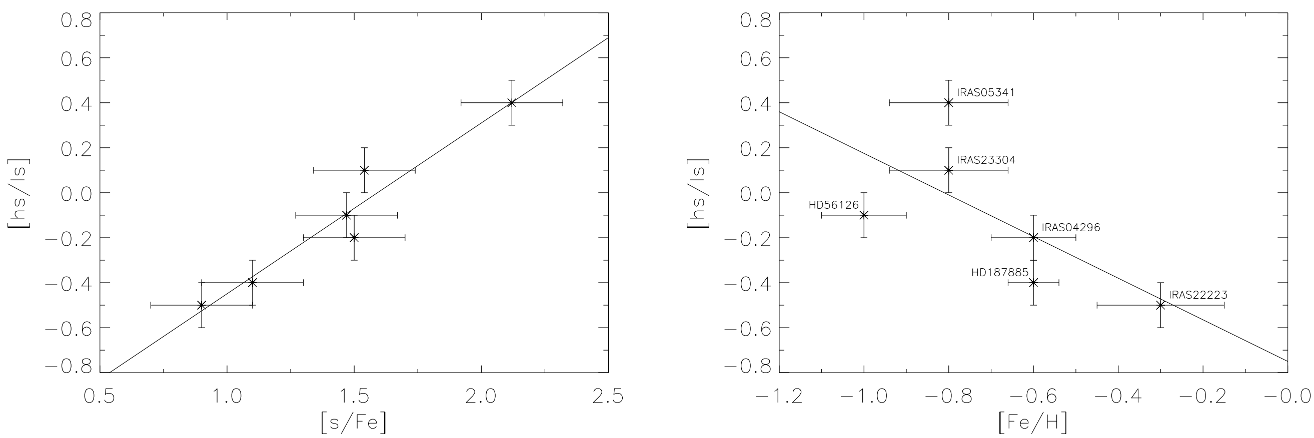

Figure 4: The [hs/ls] index as a function of the total s-process enrichment [s/Fe] *(left panel)* and as a function of metallicity [Fe/H] *(right panel).*

In Fig. 4 (left panel) a strong correlation is found between the [hs/ls] index and the total enrichment of the s-process elements as parameterised by the [s/Fe]-index, in the sense that more enriched objects also display a higher integrated neutron irradiation. Since in carbon stars the asymptotic values of the s-process distribution is probably reached (Busso et al. 1995), this means that the dredge-up efficiency is strongly linked with the neutron production in the intershell!

On the right panel of Fig. 4 the [hs/ls] index is shown as a function of metallicity. The expected trend (increasing [hs/ls] with decreasing metallicity because of the larger amount of neutrons per seed nucleus) shows a large intrinsic scatter and suggests that other fundamental parameters strongly determine the internal nucleosynthesis and dredge-up phenomena. The 21μm stars are the only intrinsically enriched objects showing a large spread in metallicity.

4.2 Comparison with Other Enriched Stars

To compare the results on the 21μm objects with other stars, we recalculated all published [hs/ls] indices so that all indices are calculated using the same species (Y, Zr, Ba, La, Nd, Sm). The s-process enhancement of the 21μm stars is compared with other intrinsic objects in Fig. 5. This enhancement turns out to be larger than in MS, intrinsic S and SC AGB stars and comparable with the enhancement in C stars. This result confirms the interpretation of the 21μm stars as post-carbon stars and strengthens the correlation between the C/O ratio (M-MS-S-SC-C sequence) and s-process enhancement.

A comparison with extrinsic (+intrinsic SC) objects (Fig. 6) shows that the neutron exposure of the 21μm stars fall roughly in the same range as the CH subgiants and is on average lower than in Ba-giants with the same metallicity. The theoretically expected trend of increasing [hs/ls] index with decreasing metallicity shows a very large intrinsic spread. Note that the weakly enriched metal deficient Ba-stars show very small [hs/ls] indices.

5 Conclusions

A complete abundance analysis has been carried out on the spectra of six 21μm sources. We confirmed their post-carbon character as they show high C/O ratios and huge carbon and

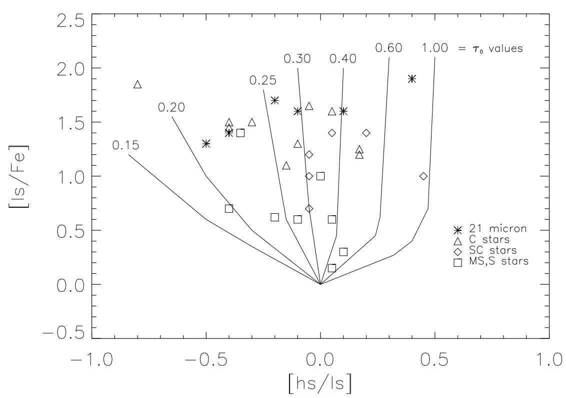

Figure 5: The enrichment of light s-process elements [ls/Fe] as a function of the neutron exposure [hs/ls]. The full lines are the theoretical predictions for different neutron exposures parameterised by τ_0 from Busso et al. (1995). Data points: see references.

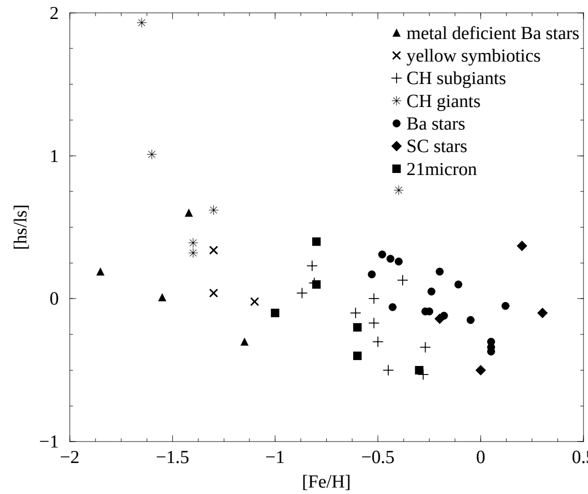

Figure 6: The [hs/ls] index for different groups of extrinsic (+intrinsic SC) stars, compared with the [hs/ls] of the 21μm stars. Data points: see references.

s-process enhancements. We further focussed on the s-process abundance distribution and found a very strong correlation between the [hs/ls] index (which is a measure for the neutron nucleosynthesis efficiency) and the total enrichment of the s-process elements (which is mainly determined by the dredge-up efficiency). The anti-correlation of the [hs/ls] index with the metallicity of the 21μm objects is less well determined and contains a large scatter. This scatter is certainly intrinsic and confirms that also other fundamental parameters strongly determine the internal nucleosynthesis and dredge-up phenomena during the AGB evolution.

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